IMPLEMENTATION OF A WATER FLOW CONTROL SYSTEM INTO THE ISS'S PLANNED FLUIDS & COMBUSTION FACILITY

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ABSTRACT

The Fluids and Combustion Facility (FCF) will become an ISS facility capable of performing basic combustion and fluids research. The facility consists of two independent payload racks specifically configured to support multiple experiments over the life of the ISS. Both racks will depend upon the ISS's Moderate Temperature Loop (MTL) for removing waste heat generated by the avionics and experiments operating within the racks. By using the MTL, constraints are imposed by the ISS vehicle on how the coolant resource is used. On the other hand, the FCF depends upon effective thermal control for maximizing life of the hardware and for supplying proper boundary conditions for the experiments.

In the implementation of a design solution, significant factors in the selection of the hardware included ability to measure and control relatively low flow rates, ability to throttle flow within the time constraints of the ISS MTL, conserve energy usage, observe low mass and small volume requirements. An additional factor in the final design solution selection was considering how the system would respond to a loss of power event.

This paper describes the method selected to satisfy the FCF design requirements while maintaining the constraints applied by the ISS vehicle.

INTRODUCTION

The Fluids and Combustion Facility (FCF) consists of two payload racks to be installed in the United States Laboratory Module of the ISS. The Combustion Integrated Rack (CIR) will be dedicated to microgravity combustion research while the Fluids Integrated Rack (FIR) is designated for microgravity fluid physics research (Figure 1). FCF will accommodate a wide variety of science experiments that will take advantage of the unique microgravity environment offered by the ISS and the facility is intended to remain operational for the duration of the ISS's orbital life. Rack infrastructure will be mostly common to both racks and consists of an International Standard Payload Rack (ISPR) outfitted with doors, environmental control system, electric power control unit, and Input/Output Processor.

To accommodate discipline specific science investigations, the CIR and FIR each have special/unique equipment (Figures 2 and 3). The combustion rack is equipped with a large combustion chamber, fuel and oxidizer delivery systems, gas chromatograph, exhaust systems, and various diagnostic packages. The fluids rack provides a large experiment surface mounting area and various diagnostics.

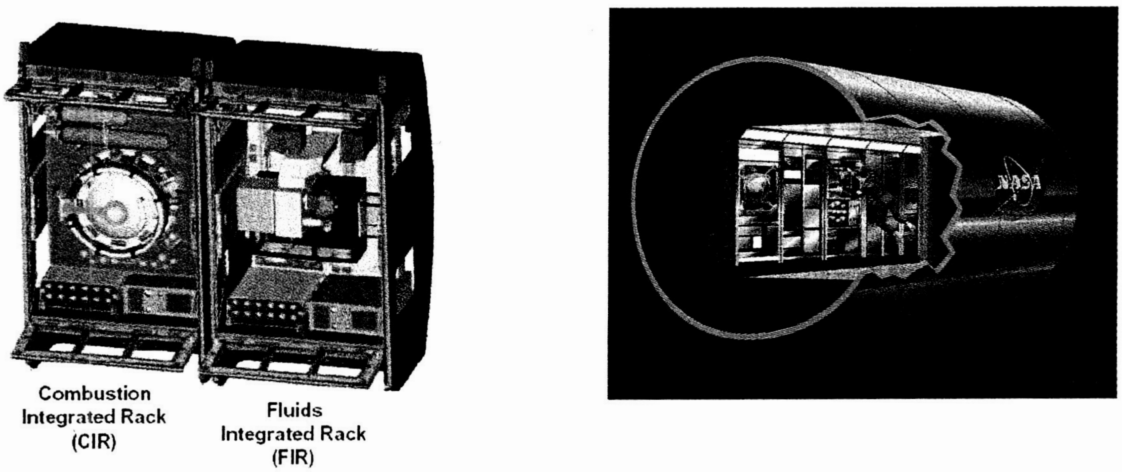


FIGURE 1: Fluids & Combustion Facility Racks, and US Laboratory Module

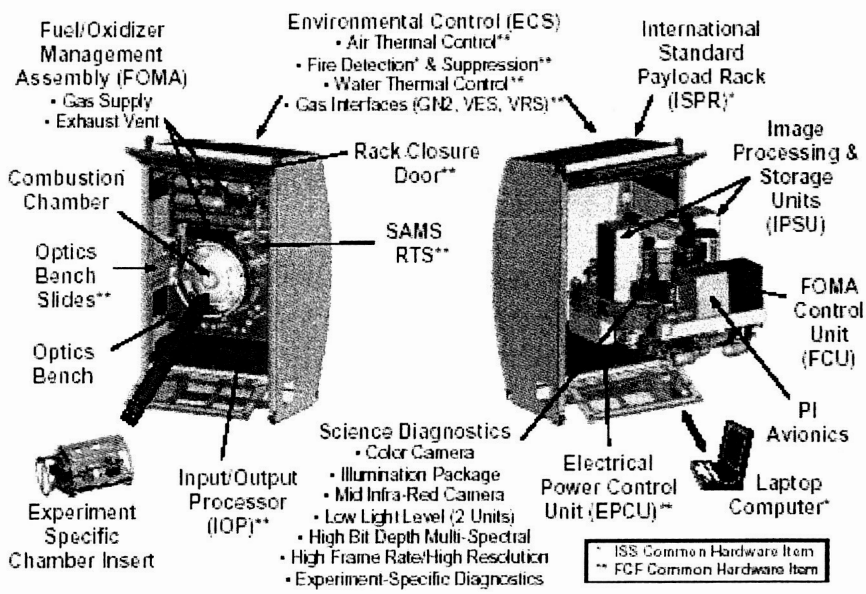


FIGURE 2: Major Components of Combustion Integrated Rack (CIR)

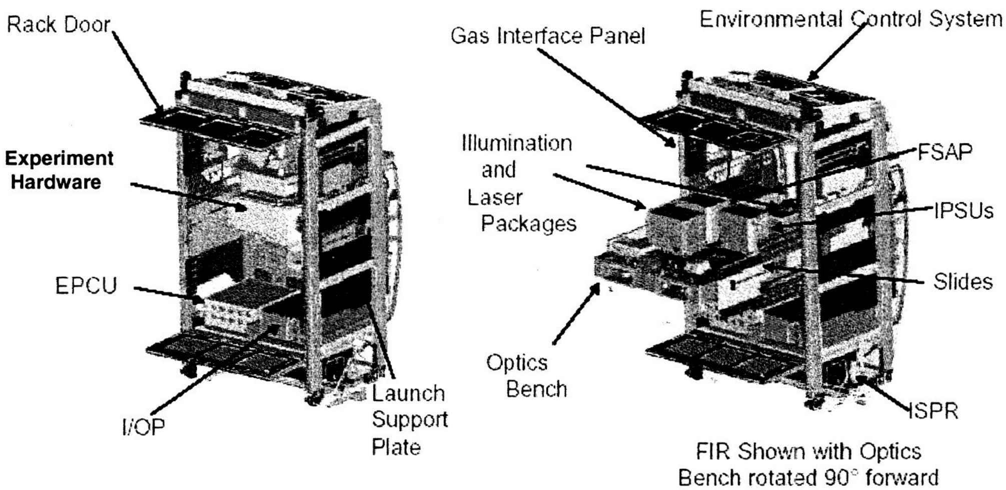


FIGURE 3: Major Components of Fluids Integrated Rack (FIR)

Rack cooling is accomplished by the Environmental Control System (ECS). The cooling method is basically the same for each rack but with subtle differences due to rack configuration.

ECS COOLING DESCRIPTION/REQUIREMENT

Each of the two racks will have similar cooling philosophies and hardware. However, the two racks are being constructed for their own specialized research resulting in some internal configuration differences. Thermal heat rejection can be made to the internal rack air, the rack's water loops, or a combination of these resources.

Heat absorbed by the circulating rack air is transferred to the water loop in the Air Thermal Control Unit's (ATCU) heat exchanger. The water also picks up heat directly from the Electrical Power Control Unit (EPCU) and in the FIR it picks up heat from Active Rack Isolation System (ARIS). Additionally, the water system has a separate parallel loop which can be used to pick up heat generated by specific experiment hardware if the hardware has been designed to interface with the water system.

In very general terms, the requirements for the FCF cooling system are:

- Provide an environmental condition to support maintainability/reliability requirements for 10-years of operation,
- Provide a stable thermal environment to support research operations,
- Conform to the constraints imposed by the ISS vehicle for utilization of the MTL cooling system.

EXPERIMENT UNIQUE HEAT SOURCES

Experiments will be widely varied over the life of the facility. Anticipating the amount of heat and the method/location for heat removal for potential future experiments is not possible. Consequently it was necessary to bound the limits of experimental heat input and provide some flexibility in how it would be removed. For the CIR, the experiments will be conducted inside the combustion chamber. Heat sources could include electronics, motors, illumination lamps, and heat of combustion. Heat removal will be via the Water Thermal Control Subsystem (WTCS) when cooling inside the chamber is required. External to the chamber, there could be unique diagnostic avionics packages. These packages will utilize the air-cooling available from the ATCU and will be required to interface through a universal mounting location on the optics bench. There is a limit for the amount of air-cooling available due to the capacity of the heat exchanger and the normal facility heat load. In the FIR, experiment heat sources will be unique to every experiment. As in the CIR, FIR will provide a range of diagnostics for customer use. The experiment unique hardware will likely include avionics, heaters, thermo-electric coolers, heat sinks, lasers, motors, and cameras.

COMMON HEAT SOURCES

Both racks include several subsystems that will always be present and sources of heat. These include the EPCU, the Environmental Control System (ECS), various command/control/communication packages, various diagnostic packages, and the numerous health & status instruments. For the FIR, there will also be the ARIS as a heat source.

ISS MTL CONSTRAINTS:

Usage of the MTL on the ISS will apply various constraints to the cooling system design. The requirements are detailed in the ISS document SSP 57000, "Pressurized Payloads Interface Requirements Document" and SSP 57001, "Pressurized Payload Hardware Interface Control Document". Some of the important constraints include:

- Materials compatibility with the cooling fluid.
- Coolant pressure drop through the integrated rack, this constraint has changed in value during the FCF project and a more challenging value of 5.8 psid (40 kPa) at any flow rate has now been applied.
- Maximum coolant flowrate of 745 lbm/hr (339 kg/hr).
- Allowable coolant return temperature rise of 35 degrees Fahrenheit above coolant supply temperature.
- Control system time constant for changes in coolant mass flow rate.

As part of the ISS coolant system, each rack location has a Rack Flow Control Assembly (RFCA) that operates in series with the rack's water system. This RFCA contains a valve for flow isolation and setting maximum water flowrate. The RFCA is controlled by the ISS vehicle with no active control capability from the individual payload rack.

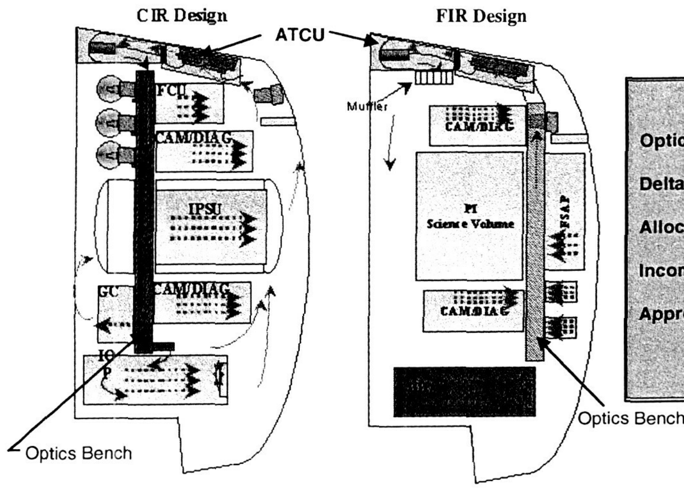
GENERAL RACK COOLING APPROACH:

As mentioned previously, one of the functions of the FCF rack's Environmental Control System is to provide the cooling necessary for the rack. Each rack is equipped with two subsystems (air and water) to provide the necessary thermal control. Both subsystems are required to be operating in order for the rack to become functional. In general, the two racks are being designed to maximize hardware commonality.

AIR THERMAL CONTROL SUBSYSTEM

The Air Thermal Control Subsystem is the main interface for heat removal of most heat dissipating components in the rack. This subsystem utilizes two centrifugal fans to circulate air in the racks and through forced convection, transfer heat from the packages to the air. The air flows across the heat exchanger, which transfers the waste thermal energy (approimately 1650 watts), into the water thermal control subsystem. Approximately 1/3 of this waste thermal energy is allocated to experiment hardware. Each rack is equipped with an optics bench which serves as the primary mounting surface for the various hardware packages. Both racks utilize their optics bench as a plenum for circulating cooling air. However, the CIR has its optics bench at the discharge of the ATCU resulting in a positively pressurized bench while the FIR has the optics bench at the inlet to the ATCU and consequently the optics bench is negatively pressurized (Figure 4).

Cooling is accomplished by air flowing over surfaces and for some packages by air flowing through. Typically avionics packages are designed for flow-through cooling. Specific sizing criteria are in place for these packages. The sizing criteria include a specified flowrate based upon package heat rejection with a specified pressure drop. Flow-through packages are attached to the optics bench. This rack air cooling design is intended to minimize microgravity disturbances by eliminating the use of fans mounted in hardware attached to the Optics Bench. The packages must comply with the criteria for the racks to succeed in thermal control. Airflow rates for the rack can be controlled but the design intends to operate at a specified flowrate for the duration of an experiment. Experiments requiring finer temperature control are expected to supply heaters, electric coolers, heat sinks, or other thermal control measures as part of the experiment.



	CIR	FIR
Optics Bench:	Positive Pressure	Negative Pressure
Delta Pressure:	0.4 inches H20	
Allocated Airflow:	0.11 CFM/watt	0.24 CFM/watt
Incoming Air Temp:	80 F (26.7 C)	86 F (30 C)
Approx. Exit Air Temp:	110 F (43.3 C)	

FIGURE 4: Airflow within the FCF Racks

WATER THERMAL CONTROL SUBSYSTEM

The Water Thermal Control Subsystem (Figure 5) is composed of a system of flex hoses, tubing, quick disconnects, flow control valves, flowrate sensors, and the ATCU heat exchanger. Ultimately, all FCF waste heat is intended to be removed by the water. The FCF will be operational over the life of the ISS and is also intended to provide services to a multitude of different users. The facility is being designed to be as flexible as possible, yet still meet the constraints of available space and services. Meeting these challenges resulted in certain design selections, including the use of flexible water hoses and quick disconnects to simplify on-orbit replacement of the ORUs that utilize the water system. Instrumentation to monitor temperature and flowrates for the water system is also included.

Two water loops are provided (primary and secondary) for heat removal. The secondary loop is dedicated to experiment specific uses and requires connection to experiment specific hardware to complete the loop. Its use is optional and will depend on the experiment. A control valve and flow sensor is provided by the FCF rack.

The primary loop is required whenever the rack is powered up. It is designed to remove up to 3.0 kW of waste thermal energy. This loop removes the heat from the ATCU heat exchanger and the EPCU cold plate (in the FIR it also cools the ARIS cold plate). Water flowrate through this loop is controlled by a Water Flow Control Assembly. The control is responsible for meeting ISS MTL constraints and for adjusting flowrate to control rack temperatures needed for FCF requirements.

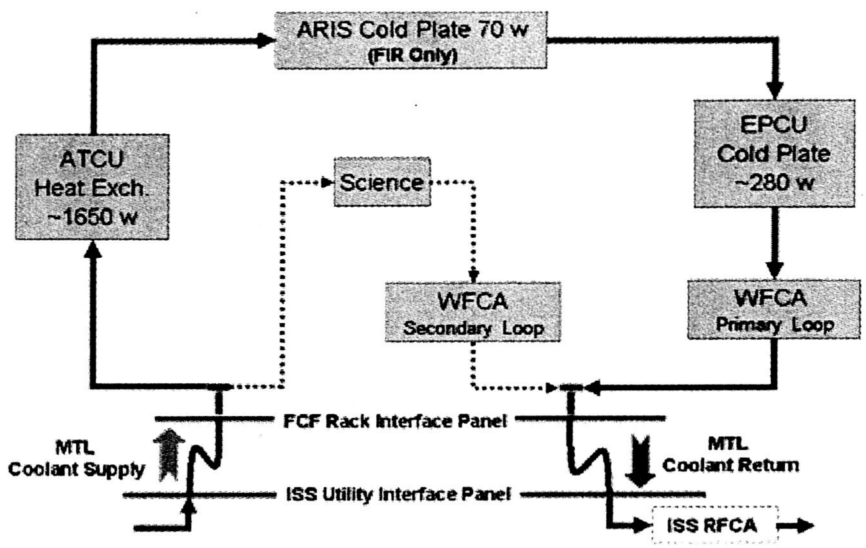


FIGURE 5: Water Flow Schematic, Example Heat Rejection Amounts

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WATER FLOW CONTROL ASSEMBLY (WFCA)

To achieve the flowrate control necessary to enhance the rack's thermal environment for research purposes, a water flow control valve is included in each water loop. The system used to control the water flowrate is called the Water Flow Control Assembly (WFCA) and its parts are shown in Figure 6. The WFCA includes three significant pieces of hardware: the control valve, the flow sensor, and the electronic controller. The three pieces are designed as a system and configured to satisfy the following major constraints:

- ability to measure and control relatively low coolant flow rates (25 to 500 lbm/hr)
- ability to throttle flow within the time constraints of the ISS MTL
- pressure drop less than 1.0 psid at 500 lbm/hr coolant flow rate
- conserve energy usage with a maximum 18.0 watts
- observe low weight (less than 5 lbs) and certain volume requirements
- An additional factor in the final design solution selection was considering how the system would respond to a loss of power event.

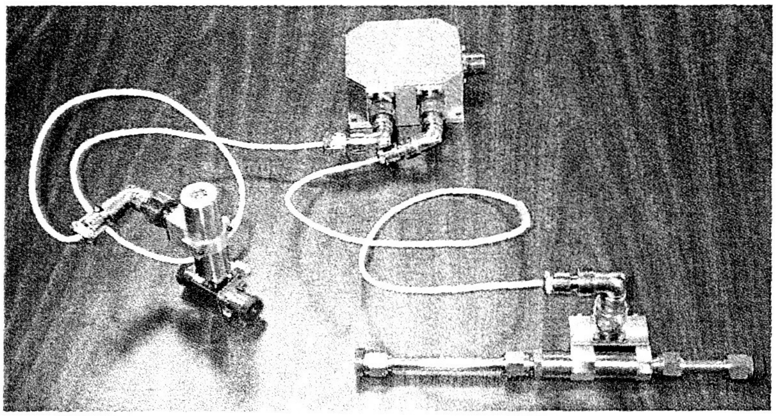

FIGURE 6: Water Flow Control Assembly

The control valve is basically a quarter turn ball valve with a stepper motor for actuation. The appeal of this combination is the ability to maintain a water flowrate without power being supplied to the valve. Since it is anticipated that a specific experiment set-point will be maintained for a substantial period of time, this characteristic was highly valued. Another important quality in the valve is the ability to throttle the coolant flowrate to within 3 lbm/hr when operating at 300 to 500 lbm/hr. This is accomplished by the stepper motor taking about 5,000 steps to go from full closed to full open.

The electronic controller has functions related to the valve and the flow sensor. To meet the ISS requirement for controlling how fast the flowrate can be changed, the stepper motor is regulated by the electronic controller so that it takes 2-minutes to transit from full open to full closed when operating at the fastest commanded speed. During periods of operation when the valve does not need to be moved, the controller does not supply power to the valve. The controller also provides power to the flow sensor and supplies a flowrate output to the main rack command/control system. The controller utilizes firmware to perform its functions.

The water flowrate sensor measures fluid flow by using a rotating turbine and supplies a value back to the main rack command/control computer for use in adjusting the valve position. Output is provided by the electronic controller in a frequency and a voltage format.

INTENDED WTCS OPERATIONAL APPROACH

The intended method of operation of the WTCS is to adjust water flow rates to match electrical power usage within the rack. In the FIR, the WTCS is also to provide temperature control of the experiment environment if necessary. Since the racks operate in an unattended mode, power usage is determined by the pre-planned sequence of events. The ISS rack flow control assembly valve will be positioned to allow maximum flow anticipated for the rack operation during the experiment. The water flow control valves located within the rack will subsequently control the water flow as determined by the control algorithm setup for that specific experiment.

Initially, there was discussion over how the valve system would be configured. It was thought that the valve, controller, and flow sensor could be a stand-alone closed-loop system where the interface command signal would be to provide a set-point water flowrate. After further consideration of potential operating scenarios, it was decided to have the valve-controller-flow sensor operate in an open-loop configuration. The loop would become closed in the main rack control systems. This would allow the operation of the water flow rate control to be configured on an experiment by experiment basis. The control could be based on projected power usage, or flowrate feedback, or temperature control, or even a combination of these techniques. This greater flexibility coupled with unknown future modes of operation of the rack, led to the selection of the open-loop configuration. On-orbit operation of the water flow control system will require the software algorithm to be fine tuned for each specific experiment and operation of the FCF rack.

SUMMARY

When coupled with the constraints of spaceflight resources, the FCF's need for flexibility and thermal control resulted in a water flow control system capable of being controlled by the individual facility racks. Through a combination of hardware, firmware, and configurable software, the FCF will be capable of supplying the general thermal needs for the expected research experiments and the facility hardware while maintaining the constraints imposed by the ISS vehicle.

NOMENCLATURE, ACRONYMS, ABBREVIATIONS

ARIS Active Rack Isolation System
ATCU Air Thermal Control Unit
CFM Cubic Feet per Minute
CIR Combustion Integrated Rack
ECS Environmental Control System
EPCU Electrical Power Control Unit
FCF Fluids and Combustion Facility
FIR Fluids Integrated Rack
ISS International Space Station
kW Kilowatts
lbm/hr Pounds mass per hour
lbs pounds
MTL Moderate Temperature Loop
ORU Orbital Replacement Unit
psid Pounds per Square Inch Differential
RFCA Rack Flow Control Assembly
WFCA Water Flow Control Assembly
WTCS Water Thermal Control Subsystem

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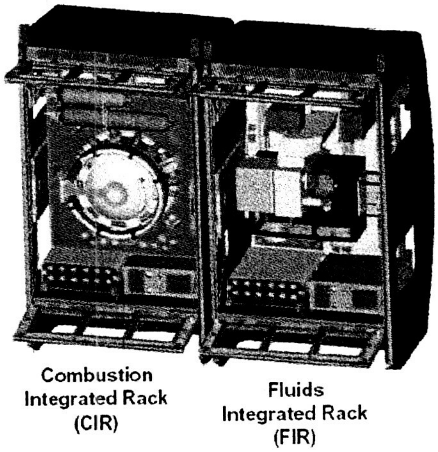


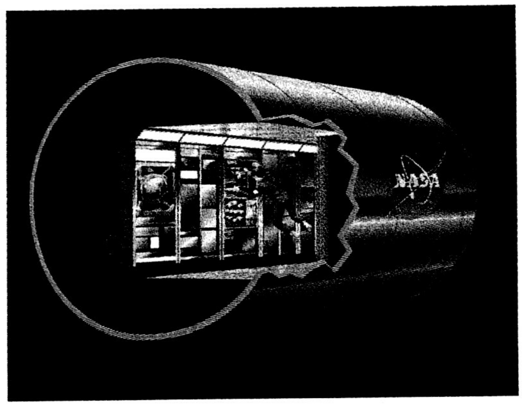


FIGURE 1: Fluids & Combustion Facility Racks, and US Laboratory Module

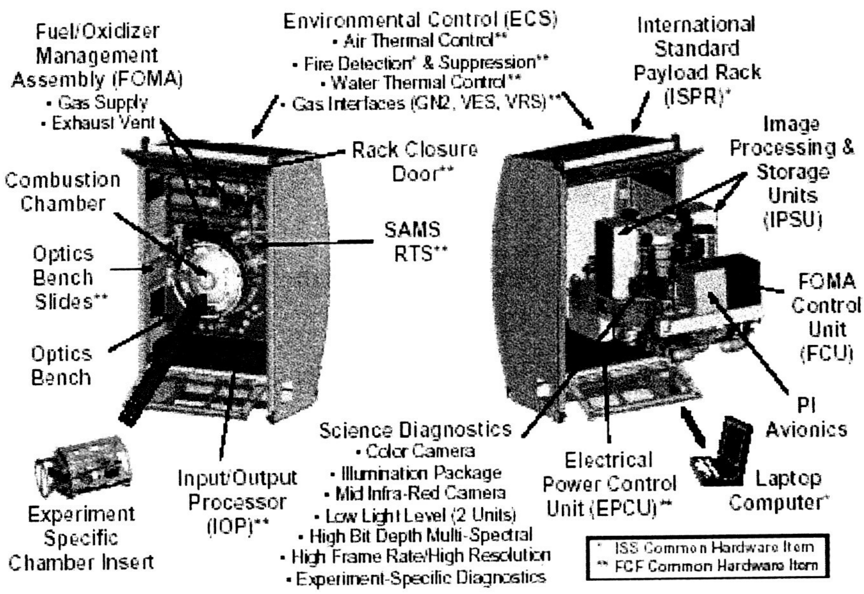
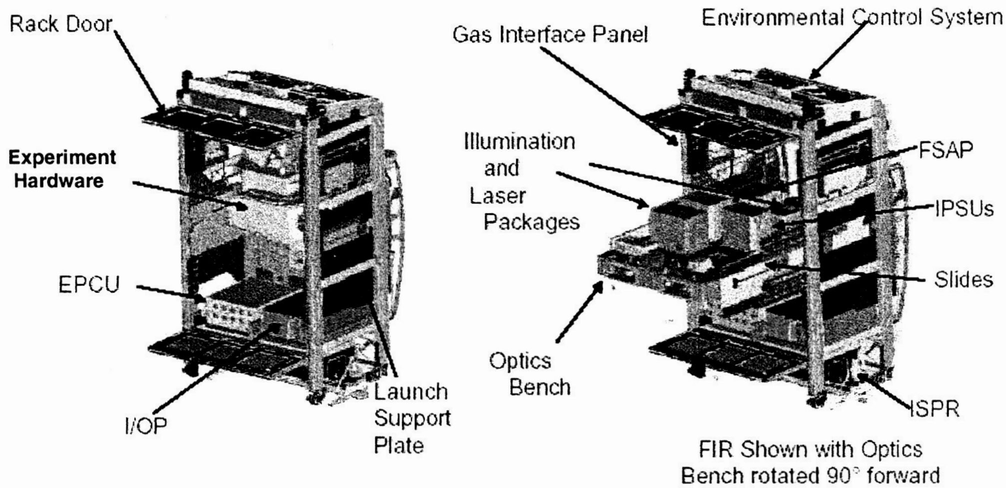


FIGURE 2: Major Components of Combustion Integrated Rack (CIR)



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Rack cooling is accomplished by the Environmental Control System (ECS). The cooling method is basically the same for each rack but with subtle differences due to rack configuration.

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Each of the two racks will have similar cooling philosophies and hardware. However, the two racks are being constructed for their own specialized research resulting in some internal configuration differences. Thermal heat rejection can be made to the internal rack air, the rack's water loops, or a combination of these resources.

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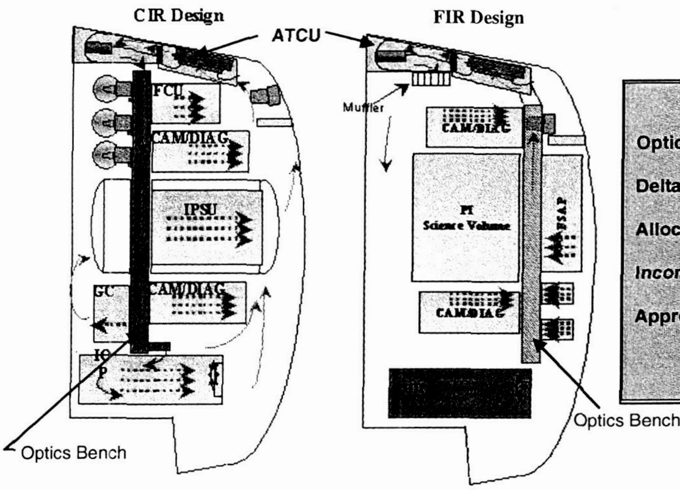

	CIR	FIR
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FIGURE 4: Airflow within the FCF Racks

WATER THERMAL CONTROL SUBSYSTEM

The Water Thermal Control Subsystem (Figure 5) is composed of a system of flex hoses, tubing, quick disconnects, flow control valves, flowrate sensors, and the ATCU heat exchanger. Ultimately, all FCF waste heat is intended to be removed by the water. The FCF will be operational over the life of the ISS and is also intended to provide services to a multitude of different users. The facility is being designed to be as flexible as possible, yet still meet the constraints of available space and services. Meeting these challenges resulted in certain design selections, including the use of flexible water hoses and quick disconnects to simplify on-orbit replacement of the ORUs that utilize the water system. Instrumentation to monitor temperature and flowrates for the water system is also included.

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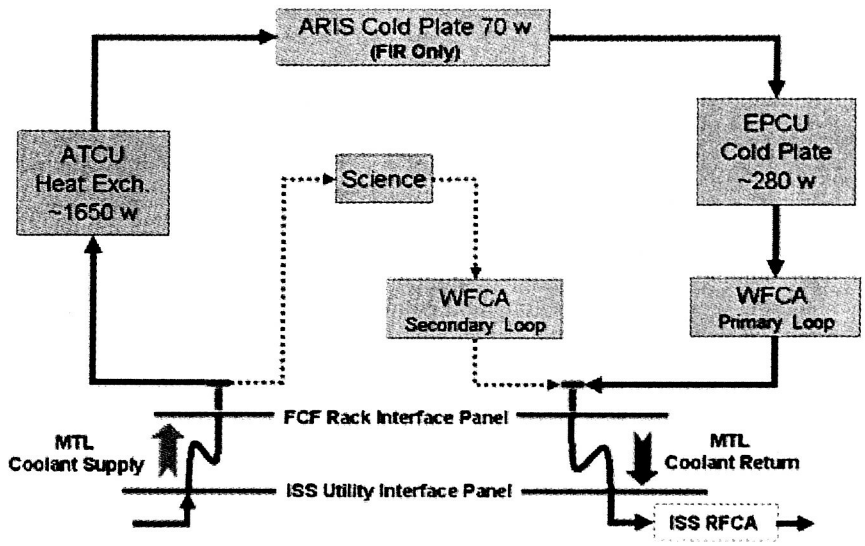

FIGURE 5: Water Flow Schematic, Example Heat Rejection Amounts

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WATER FLOW CONTROL ASSEMBLY (WFCA)

To achieve the flowrate control necessary to enhance the rack's thermal environment for research purposes, a water flow control valve is included in each water loop. The system used to control the water flowrate is called the Water Flow Control Assembly (WFCA) and its parts are shown in Figure 6. The WFCA includes three significant pieces of hardware: the control valve, the flow sensor, and the electronic controller. The three pieces are designed as a system and configured to satisfy the following major constraints:

- ability to measure and control relatively low coolant flow rates (25 to 500 lbm/hr)
- ability to throttle flow within the time constraints of the ISS MTL
- pressure drop less than 1.0 psid at 500 lbm/hr coolant flow rate
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- observe low weight (less than 5 lbs) and certain volume requirements
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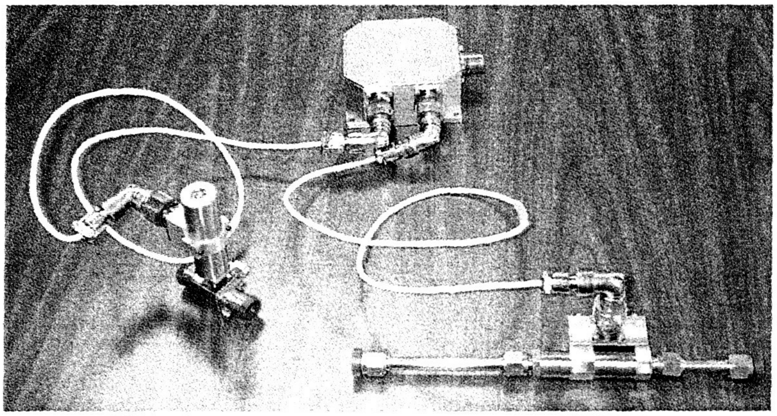

FIGURE 6: Water Flow Control Assembly

The control valve is basically a quarter turn ball valve with a stepper motor for actuation. The appeal of this combination is the ability to maintain a water flowrate without power being supplied to the valve. Since it is anticipated that a specific experiment set-point will be maintained for a substantial period of time, this characteristic was highly valued. Another important quality in the valve is the ability to throttle the coolant flowrate to within 3 lbm/hr when operating at 300 to 500 lbm/hr. This is accomplished by the stepper motor taking about 5,000 steps to go from full closed to full open.

The electronic controller has functions related to the valve and the flow sensor. To meet the ISS requirement for controlling how fast the flowrate can be changed, the stepper motor is regulated by the electronic controller so that it takes 2-minutes to transit from full open to full closed when operating at the fastest commanded speed. During periods of operation when the valve does not need to be moved, the controller does not supply power to the valve. The controller also provides power to the flow sensor and supplies a flowrate output to the main rack command/control system. The controller utilizes firmware to perform its functions.

The water flowrate sensor measures fluid flow by using a rotating turbine and supplies a value back to the main rack command/control computer for use in adjusting the valve position. Output is provided by the electronic controller in a frequency and a voltage format.

INTENDED WTCS OPERATIONAL APPROACH

The intended method of operation of the WTCS is to adjust water flow rates to match electrical power usage within the rack. In the FIR, the WTCS is also to provide temperature control of the experiment environment if necessary. Since the racks operate in an unattended mode, power usage is determined by the pre-planned sequence of events. The ISS rack flow control assembly valve will be positioned to allow maximum flow anticipated for the rack operation during the experiment. The water flow control valves located within the rack will subsequently control the water flow as determined by the control algorithm setup for that specific experiment.

Initially, there was discussion over how the valve system would be configured. It was thought that the valve, controller, and flow sensor could be a stand-alone closed-loop system where the interface command signal would be to provide a set-point water flowrate. After further consideration of potential operating scenarios, it was decided to have the valve-controller-flow sensor operate in an open-loop configuration. The loop would become closed in the main rack control systems. This would allow the operation of the water flow rate control to be configured on an experiment by experiment basis. The control could be based on projected power usage, or flowrate feedback, or temperature control, or even a combination of these techniques. This greater flexibility coupled with unknown future modes of operation of the rack, led to the selection of the open-loop configuration. On-orbit operation of the water flow control system will require the software algorithm to be fine tuned for each specific experiment and operation of the FCF rack.

SUMMARY

When coupled with the constraints of spaceflight resources, the FCF's need for flexibility and thermal control resulted in a water flow control system capable of being controlled by the individual facility racks. Through a combination of hardware, firmware, and configurable software, the FCF will be capable of supplying the general thermal needs for the expected research experiments and the facility hardware while maintaining the constraints imposed by the ISS vehicle.

NOMENCLATURE, ACRONYMS, ABBREVIATIONS

ARIS	Active Rack Isolation System
ATCU	Air Thermal Control Unit
CFM	Cubic Feet per Minute
CIR	Combustion Integrated Rack
ECS	Environmental Control System
EPCU	Electrical Power Control Unit
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
ISS	International Space Station
kW	Kilowatts
lbm/hr	Pounds mass per hour
lbs	pounds
MTL	Moderate Temperature Loop
ORU	Orbital Replacement Unit
psid	Pounds per Square Inch Differential
RFCA	Rack Flow Control Assembly
WFCA	Water Flow Control Assembly
WTCS	Water Thermal Control Subsystem